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Global oceanic wind speed trends

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ABSTRACT

This study presents the regional and seasonal climatic trends of the global oceanic sea surface wind speed for the period 1988–2011 using Cross-Calibrated, Multi-Platform (CCMP) wind data. The relationship between important factors (nino3 and soi index) and occurrences of wind speed is also calculated, in hope of providing references for the analysis of global climate change, development of offshore wind energy resources, air–sea interactions, and the basic reference helping for the mid-long term prediction of sea surface wind speed and occurrences of wind speed. The analysis results show that (1) The global oceanic sea-surface wind speeds increased at a significant overall rate of 3.35 cm s^{-1} yr^{-1} for the period 1988–2011; the maximal rate of increase, 4.15 cm s^{-1} yr^{-1}, was attained between 1991 and 2007. (2) Globally, the sea-surface wind speeds significantly increased from 1988 to 2011. Only a few sporadic small water bodies exhibited decreasing wind speeds without significant variation over the 24-year interval. (3) The sea-surface wind speeds displayed obvious regional variability. The increasing wind speeds were more noticeable over the Pacific low-latitude waters than over waters of higher latitude. Wind speeds trends over the western Atlantic waters were stronger than those over the eastern Atlantic waters, while the south Indian Ocean winds were stronger than that those over the north Indian Ocean. (4) The variation in sea-surface wind speeds demonstrated noticeable seasonal differences. The increasing wind speed trend over the winter hemisphere was stronger than the one over the summer hemisphere. The variation in wind speeds over different waters was seasonally dominated. The increasing trend over the coastal waters of southern Greenland was dominated by the MAM and SON, was dominated by DJF in the Davis Strait and the Mediterranean, and was dominated by the SON 10° N over the Pacific Ocean and over the high-latitude waters in the southern Indian Ocean.

1. Introduction

Given the current ongoing environmental and resource issues, it is necessary to investigate the impact of global climate change. Oceans play a vital role in the global carbon cycle, and they are important regulators of the world's climate (Wang et al., 2008; Suarez et al., 2014; Spalding et al., 2014). Oceans also control the long-term marine trends, including the sea-surface wind field, and are a key point of study with respect to climate variability and change (Shapiro et al., 2010; Tkalich et al., 2013). Valipour (2014a,b,c,d) has pointed out that the wind speed may effect the evapotranspiration, thus resulting in a significant impact on the solar radiation, crop and so on. The long-term trends of the sea-surface wind speeds also have a significant impact on wind energy development and utilization and air–sea interactions.

Researchers have made great contributions toward the analysis

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Abbreviations: ADEOS-II, the second Japanese Advanced Earth Observing Satellite; AMSR-E, Advanced Microwave Scanning Radiometer for Earth Observing System; CC, correlation coefficient; CCMP, Cross-Calibrated, Multi-Platform; COADS, Comprehensive Ocean-Atmosphere Data Set; DJF, December, January, February; ERA-40, 40-yr ECMWF Re-Analysis; JJA, June, July, August; MAM, March, April, May; NAO, North Atlantic Oscillation; NCEP, U.S. National Center for Environmental Prediction; PO.DAAC, Physical Oceanography Distributed Active Archive Center; QuikSCAT, Quick Scatterometer; READER, Reference Antarctic Data for Environmental Research; RSS, Remote Sensing Systems; SON, September, October, November; SSM/I, Special Sensor Microwave Imager; TMI, Tropical Rainfall Measuring Mission Microwave Imager; VAM, variational analysis method.

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of long-term sea-surface wind speed trends. Gulev and Hasse (1999) and Gulev and Grigorieva (2004) determined that there were no significant long-term changes in the sea-surface wind speeds near the equator, and that wind speeds rates increased far less over the tropical South Atlantic and subtropical North Pacific. Using Comprehensive Ocean-Atmosphere Data Set (COADS) data, Ward and Hoskins (1996) found that sea-surface wind speeds displayed an upward trend over the tropical North Atlantic and the extratropical North Pacific, and a downward trend over the equatorial and tropical South Atlantic and subtropical North Pacific between 1949 and 1988. Using WASA reanalysis, Gunther et al. (1998) investigated trends in wind speeds for the northeast Atlantic region. For the period of 1955–1994, slight increases in wind speed (3.2 cm s^{-1} yr^{-1} for the 99th percentile and 2.6 cm s^{-1} yr^{-1} for the 90th percentile) were reported for the northern parts of the North Sea. From 1977 to 1999, an apparent increasing trend in sea-surface wind speeds, of about 0.2 cm s^{-1} yr^{-1}–3.5 cm s^{-1} yr^{-1}, was identified by Gower (2002) using buoy data. Turner et al. (2005) used the Reference Antarctic Data for Environmental Research (READER) project data set, which contains monthly mean Antarctic near-surface wind speed data, to investigate trends in wind quantity over the last 50 years for 19 stations with long data records. Their results showed that eight of these stations experienced wind speed increases over their periods of operation, with only two coastal stations having experienced wind speed decreases. Thomas et al. (2008) pointed out that for the period of 1982–2002, the wind speed trends remained within the annual mean for spatially averaged adjusted winds, 4 cm s^{-1} yr^{-1} for estimated speeds and 2 cm s^{-1} yr^{-1} for measured speeds, over most of the global oceans. Cox and Swail (2001) analyzed the variation in global wind speeds using the U.S. National Center for Environmental Prediction (NCEP) global hindcast. With respect to mean wind speeds, significant increases were found over the northeast Atlantic and the southern Ocean (latitudes of greater than 50° S). A substantial mean wind speed decrease was noted over the tropical and subtropical Pacific. Recently, Sterl and Caires (2005) analyzed the variation of the global wind speeds for the period of 1971–2000 using ERA40 reanalysis. Maximum increasing rates of 6 cm s^{-1} yr^{-1} for the mean and 12 cm s^{-1} yr^{-1} for the 99th percentile wind speeds were found over the equatorial Pacific and the Southern Oceans during the winter (January). These results are similar in magnitude and pattern to the results reported by Gunther et al. (1998), where the trend in mean wind speeds showed an increase in magnitude of about 0.5 cm s^{-1} yr^{-1}–1.0 cm s^{-1} yr^{-1} over the vast majority of the northern hemisphere's oceans.

However, there has been little research into long-term global oceanic sea-surface wind speed trends. This study aims to ascertain the long-term global oceanic sea-surface wind speed trends over a 24-year interval, from 1988 to 2011, at the 0.25° × 0.25° grid point using a CCMP wind field. This study will also determine the regional and seasonal differences in these global long-term trends.

2. Methodology and data

Based on the CCMP wind data for the period 1988–2011, this study presents the regional and seasonal characteristics of the long term trend of global oceanic sea surface wind speed. The long term trends of occurrences of wind speeds greater than Class 5 and greater than Class 6 are also calculated. Then the relationship between important factors (nino3 and soi index) and occurrences of wind speed is calculated, in hope of providing references for the analysis of global climate change, development of offshore wind energy resources, air–sea interactions, and the basic reference helping for the mid-long term prediction of sea surface wind speed and occurrences of wind speed.

The CCMP ocean surface wind product is hosted at the Physical Oceanography Distributed Active Archive Center (PO.DAAC) and has been evaluated and utilized extensively by the scientific community (Atlas et al., 2011). The data is derived through cross-calibration and assimilation of ocean surface wind data from the Special Sensor Microwave Imager (SSM/I), Tropical Rainfall Measuring Mission Microwave Imager (TMI), the Advanced Microwave Scanning Radiometer for Earth Observing System (AMSR-E), SeaWinds on Quick Scatterometer (QuikSCAT), and SeaWinds on the second Japanese Advanced Earth Observing Satellite (ADEOS-II). Cross calibration is performed by Remote Sensing Systems (RSS) under the purview of the DISCOVER project. These data sets are combined with conventional observations and a starting estimate of the wind field using a variational analysis method (VAM). The VAM requires a background (or first guess) analysis of gridded u and v wind components as a priori estimate of the wind field (Zheng and Pan, 2014; Zheng and Li, 2015; Zheng et al., 2016). The 40-year ECMWF Re-Analysis (ERA-40) is used as the background for the period of July 1987 to December 1998. Beginning in 1999, with the benefit of four-dimensional variational data assimilation (4DVAR) and increased spatial resolution, the ECMWF operational (ECOP) analysis outperformed the ERA-40 and was used in this study as the background analysis. The ECOP time resolution is 6 h intervals, and its spatial resolution is 0.25° × 0.25° over the time range from July 1987 to July 2011 and a space range of 78.375° S–78.375° N and 0.125° E–379.875° E.

CCMP wind production has been proven to have high precision. Carvalho et al. (2013) compared ocean surface wind data derived from several QuikSCAT products and the CCMP project to experimental wind speed and direction measurements. Their results showed that CCMP is able to bring about substantial improvements in terms of wind direction temporal variability and wind speed mean state. Kent et al. (2013) made a comparison between 12 different monthly mean wind speed datasets for the period of 1987–2009. They pointed out that the in situ and reanalysis datasets presented stability-dependent, earth-relative wind speeds that were adjusted to a reference level of 10 m. The satellite and blended datasets presented neutral, equivalent surface-relative wind speeds that were adjusted to a reference level of 10 m. Differences between these wind speed estimates depended upon the atmospheric stability and the oceanic currents and could be greater than was necessary for targeting accuracy. The stability adjustment is itself uncertain; however, these uncertainties are likely to be smaller than the biases caused when stability effects are neglected. Carvalho et al. (2015) compared the offshore wind data derived from satellite measurements (CCMP, QuikSCAT, NCDC Blended Sea Winds, and IFREMER Blended Wind Fields), reanalyses (NCEP-CFSR, ERA-Interim, NASA-MERRA, and NCEP-RII), analyses (NCEP-FNL and NCEP-GFS), and WRF modeled offshore winds with in situ measurements at five buoys moored along the Iberian Peninsula Atlantic coast. Offshore wind data taken from CCMP was found to have the lowest error for mean wind speed estimation.

3. Results

3.1. The overall long-term trend

Regional averages for the global oceanic sea-surface wind speeds were determined from 1988 to 2011, and then the long-term global oceanic wind speed trends were assessed as a whole (Fig. 1a).

Using linear regression, a relationship coefficient, $|r| = 0.96 > r_{0.01} = 0.51$, of 0.0325 passed the 99% reliability test. Thus, the sea-surface wind speeds demonstrated a significant trend, increasing at a rate of 0.0325 m s^{-1} yr^{-1} (3.25 cm s^{-1} yr^{-1}) over the global oceans within the last 24 years. Annual average